THE NEWBURY VOLCANICS

by

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ABSTRACT

The Newbury volcanics form a belt in northeast Massachusetts extending from the mouth of the Island river on the coast southwestward 17 miles toward Boston. The volcanics are divided into 4 members which are from bottom to top: Lower Rhyolite, Andesite, Upper Rhyolite and Basalt. Lenses of slate and conglomerate as well as thin beds of fossiliferous, calcareous sediments occur intercalated in the Andesite member.

The structure of the belt is interpreted as a northeast striking homocline dipping steeply to the northwest. The southeast contact is considered to be a non-conformity while the northwest one is assumed to be a fault contact. After a sharp bend in the strike to the south, near Governor Dummer Academy, the members of the volcanics are cut out one by one by faults on the northwest side of the belt. However 3 1/4 miles further to the southwest exposures of the Lower Rhyolite and the Andesite are found again in the Topsfield-Middleton area.

Based on fossils found in both the Newbury-Rowley and Topsfield-Middleton areas the age of the Newbury volcanics is placed between Upper Silurian and Lower Devonian with Upper Silurian age being however the most probable.

The volcanic series reaches its maximum thickness, estimated at 11,580 feet, on the northeasternmost portion of the belt.

Due to similarity in field appearance, mineralogy, lithologic types, degree of alteration and bulk chemical composition the Newbury volcanics are considered as belonging to the same volcanic cycle as the Lynn and Mattapan volcanics of the Boston area.

The Newbury volcanic belt is surrounded by a complex of older intrusive igneous rocks. Those igneous rocks include the Dedham granodiorite-granite and the Newburyport quartz-diorite.

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INTRODUCTION

Location and Accessibility

The area under investigation is located in northeastern Massachusetts and extends through the southwestern corner of the Newburyport East quadrangle, the southeastern corner of the Newburyport West quadrangle, the Northwestern corner of the Ipswich quadrangle and the northeastern quarter of the Georgetown quadrangle, including areas of Newbury, Rowley, and Ipswich townships (Plate 8). To the southwest another strip of those volcanics occurs between Topsfield and Middleton, southeast of the junction of the Georgetown, Salem and Reading quadrangle.

The area can be reached from Boston by route 1 (Newburyport Turnpike) or route 1A.

General Geologic Setting

The Newbury volcanics belong to a broader belt of igneous rocks which covers most of the eastern part of Massachusetts. The Newbury rocks are surrounded by an older igneous complex including granites, granodiorites and diorites.

Topography

The topography on the northeastern part of the volcanic belt, along the Parker river, is dominated by tidal marshes and fields cut by ridges parallel to the strike of the volcanics. In places the dominant features are drumlins. In this part of the belt the outcrops are more abundant due to the ridges formed by the volcanics. Outcrops are found also around and, sometimes, on the top of drumlins.

Toward the southwest the topography changes radically. Marshes become less widespread and appear as isolated spots between drumlins. The ridges almost disappear south of Weatherfield road, where very few isolated ridges are found. The prominent features in this part of the section are low, knobby hills of till resulting from partial erosion of drumlins. Just south of Haverhill street, the Hunsley Hills, which are elongated drumlins, 220 feet high, with their long axes oriented approximately N 50 W, are the dominant features. Due to the extensive glacial deposits in this area, outcrops become very reduced in number and in size.

On the volcanic strip between Topsfield and Middleton marshes are virtually absent and NW oriented drumlins cover almost the entire area. West of Middleton Colony, however, a NE trending ridge is formed by the Andesite member of the Newbury volcanics. This ridge forms the southwesternmost outcrops of the volcanics in the Topsfield-Middleton area.

Previous work

The first reference to the volcanics of the Newbury area was by Hitchcock (1835) when he wrote about the porphyries in Massachusetts: "Only three ranges of this rocks are given on the map; and these are all in the eastern of the State. Two of them,- the principal ones, - lie, the one on the north and the other on the south of Boston, having their longitudinal direction east west. The third is in Essex county, extending easterly from Byfield Academy, nearly or quite to the coast. This strip is chiefly compact feldspar and mostly the red variety."

The strips mentioned by Hitchcock are respectively the Lynn, Mattapan and Newbury volcanics.

In 1880 Crosby studied the rocks of the Newbury area under the name of Petrosilex. He published a chemical analysis of the Lower Rhyolite member of the volcanics.

Sears studied the area in 1888 and 1905, and considered the volcanics of the Newbury-Rowley area as equivalent to the Lynn Volcanics.

Although not discussing the structure of the volcanics in particular, Ball and Clapp (1905) suggested by their cross section of the area, that those rocks occupy a tightly folded, elongated syncline.

A fossil locality was reported by Keith in 1915 at Glen Mills at the SE corner of the junction of Central street with the Newburyport Turnpike. The fossiliferous bed is a thin (3 inches), calcareous shale, between an andesite flow below and an agglomeratic tuff above.

The volcanics were mapped by Emerson (1917) as Newbury Volcanic Complex and were regarded by him as older than the typical Lynn volcanics.

C. Clapp (1921) again included the volcanics of the Parker river area as part of the Lynn volcanics, and considered the Newbury volcanic belt as a relatively broad synclinal fold along whose limbs considerable faulting took place.

Cecil Schneer (1951) in an unpublished U.S.G.S. report on the extreme northeastern end of the volcanics, interpreted them as an elongated northeasterly plunging syncline with the southeastern border resting unconformably on the Dedham granodiorite and the northeastern border in fault contact with the same granodiorite. He worked out for the first time a stratigraphy for the volcanics dividing them into five members which are, from bottom to top: basalt, rhyolite, lower andesite, slates and conglomerates, and upper andesite.

In 1958 J. McCarthy studied the Newbury volcanics from their northeasternmost outcrops as far as Weatherfield street in the northeastern corner of the Georgetown quadrangle. He concluded that the over-all structure of the area is a "single succession of homoclinally dipping formations". On the basis of this new interpretation he divided the volcanics into foursmembers which are, from bottom to top: lower rhyolite, andesite, upper rhyolite and basalt; slate and conglomerate were considered as occurring as lenses in the andesite.

Toulmin (1958) in his work on the bedrock geology of the Salem area, mapped a strip of eruptives between Topsfield and Middleton that he recognized as belonging to the Newbury volcanics. No attempt was made to establish a direct stratigraphic correlation of the volcanics that he called "andesitic greenstone" with the volcanics of the Newbury-Rowley area.

Purpose of investigation.

The purpose of this work is to continue the field investigation of the volcanics from Weatherfield street to the south, review McCarthy's and Toulmin's areas, carry out petrographic work on the rocks of those areas, summarize the present knowledge of the Newbury volcanics and try to establish the correlation of those rocks with the Lynn and Mattapan volcanics of the Boston area.

Acknowledgement.

I am deeply grateful to Professor Arthur J. Boucot for his encouragement and assistance. I wish also to express my thanks to Professor William F. Brace for his assistance in the initial phase of this work.

S T R A T I G R A P H Y

NEWBURY VOLCANICS

The name Newbury for the volcanics under study was first used by Emerson (1917) who mapped those rocks as Newbury Volcanic Complex. The designation came from the township of Newbury on the northeast of the belt where the volcanics are well exposed.

A typical section of the volcanics can be seen along the Newburyport Turnpike from 0.7 miles south of Dodge corner to the Parker river.

The Newbury volcanics comprise four members which are from bottom to top: Lower Rhyolite, Andesite, Upper Rhyolite and Basalt. These designations are based on Schneer's petrographic work (1951). Although the extent of alteration of the more mafic members of the series prevents a definite distinction between them, the designations of Basalt and Andesite will be used in this work for stratigraphical purposes only.

With exception of the Lower Rhyolite all the members tend to thicken northwestward. The maximum thicknesses, east of Newbury Old Town are:

Basalt	3000'
Upper Rhyolite	2200'
Andesite	5800'
Lower Rhyolite	580'

Just east of Governor Dummer Academy, where the strike of the whole series changes abruptly to the south the estimated thicknesses are:

Basalt	2000'
Upper Rhyolite	2000'
Andesite	1800'
Lower Rhyolite	600'

The slate and conglomerate which occur as lenses in the Andesite, attain a thickness of 300' in places, as just southwest of Newman road on the benches of the Little river. Usually, however, the thickness of these lenses does not exceed 100'.

Lower Rhyolite member

A typical section of this member can be seen along the Newburyport Turnpike just south of Dodge Corner.

The Lower Rhyolite is a relatively thin unit (600') at the base of the Newbury volcanics. The nature of its contact with the basement complex was never directly observed although in places as along the Blue Star Memorial Highway, the Lower Rhyolite crops out within 200' of the Dedham granodiorite. This contact is assumed to be an unconformity.

The Lower Rhyolite is overlain conformably by the Andesite member. In the northeastern part of the belt the contact is better defined than southwestward where outcrops are more scarse.

In the Newbury-Rowley area the Lower Rhyolite extends southwestward further than any other member of the volcanics. To the southwest of that area, along the Blue Star Memorial Highway, close to the junction of the Rowley

Hill street and the Bridge road, outcrops of this unit are found again.

The Lower Rhyolite is usually massive but in places has irregular obscure flow banding. When fresh, it is chiefly pinkish brown to dark purplish brown, but occasionally shows a creamish white color. The rhyolite is porphyritic, showing 15 to 20% quartz and 10 to 15% sanidine phenocrysts in hand specimen. Very dark green patches, produced by chloritic alterations of ferromagnesian minerals, are commonly observed on fresh surfaces of the rock. Locally intensive fracturing allows a deep penetration by weathering, rendering it difficult to get a fresh sample. The weathered surfaces along the fracture planes are a dull yellowish color due to limonitic alteration of hematite, magnetite and pyrite. On the external surface, where the iron compounds are carried away more easily in solution, the weathered zone is typically a thin, light pinkish brown kaolinitic layer. In places where kaolinitic material has been partly removed, patches of quartz stand up.

Microscopic fabric:- The thin sections show phenocrysts of quartz and sanidine immersed in a microcrystalline groundmass. The rhyolite of the Newbury-Rowley area shows typically myrmekitic texture with elongated crystals of sanidine, usually rectangular in thin section, surrounded by a star-like structure formed by the intergrowth of sanidine with quartz. Some quartz phenocrysts are surrounded by a layer of very fine grained quartz crystals; the microcrystalline quartz of this perypheral layer has simultaneous extinction with the phenocryst. Limonite originated from alteration of pyrite and hematite is disseminated between grains and in small veins along fractures. Along the fractures, the heavily limonitic zone is 1 to 2 mm deep. The rock has in general a equigranular, merocrystalline, hyppidiomorphic-granular texture.

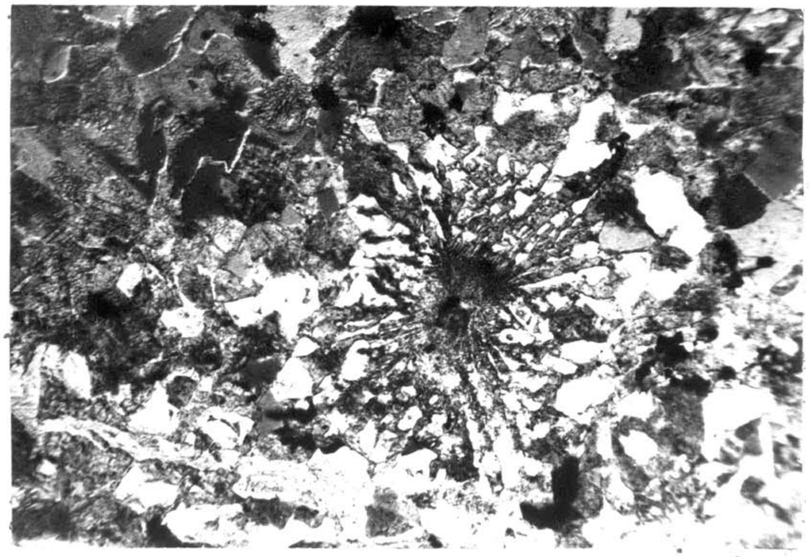

Fig 1 - Myrmekitic texture. Crossed Nichols. X 45.

The rhyolite from the Blue Star Memorial Highway is also porphyritic, but here it contains also albite as phenocrysts besides quartz and sanidine. The proportion of sanidine as phenocrysts is greater than that of quartz; sanidine phenocrysts form about 6% of the rock, quartz phenocrysts only about 1% and albite about 1%. The groundmass here is cryptocrystalline to microcrystalline. Ferromagnesian minerals have been completely altered to chlorite, saussurite and calcite; phenocrysts of plagioclase and sanidine have been partly replaced by those minerals. Complete alteration of amphibole left concentrated areas of hematite. This rhyolite lacks myrmekitic structures. Flow structure is very conspicous showing drag around phenocrysts as shown in figure 2.

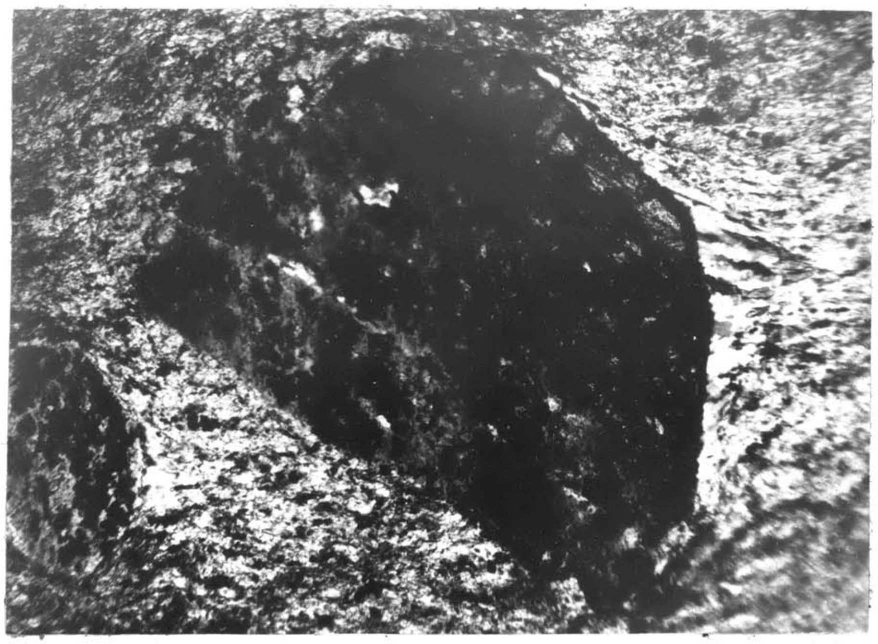

Fig 2.- Flow structure. Crossed Nichols.
X 45.

Although the microscopic examination of this rock shows an over-all texture different from those observed in the Lower Rhyolite to the north, the correlation is based on field appearance and stratigraphic position and confirmed by similarity of X-ray powder picture.

Crosby (1880 p. 58) published a chemical analysis of rhyolite from the Bartlett Mine, south of Parker river and near the road leading south from Newbury Old Town. This locality, near Mud creek, is in the Lower Rhyolite belt.

The analysis, which was made by Miss E. W. Walton, shows the following results:

SiO_2	77.200%
Al_2O_3	12.482
Fe_2O_3	1.570
CaO	.800

K_2O	1.230%
Na_2O	4.423
H_2O	2.004
MnO	trace
Total	99.709

The proportion of Na_2O shows that the rock is a soda rich rhyolite; the fact that the soda does not appear as albite, which makes up only a small fraction of the Lower Rhyolite phenocrysts, suggests that the soda may be associated with potassium feldspars. The high temperature feldspar sanidine may hold a fair amount of soda and thus it is reasonable to assume that this mineral is the dominant feldspar of the Lower Rhyolite.

The major constituents of the rhyolite are quartz, sanidine and albite with sanidine as the predominating feldspar.

The secondary minerals are hematite, magnetite, ilmenite, pyrite, limonite, leucoxene, sericite, calcite, saussurite and chlorite. (See appendix No. 1, 2 and 3)

Andesite member

The Andesite is the most complex member of the Newbury volcanics. A fairly representative section of this unit is here designated on the Newburyport Turnpike, from Glen Mills to the benches of the Mill river. The Andesite has a thickness of 5,800 feet in the northeastern end of the belt, but it narrows toward the southwest reaching 1,800 feet just east of Governor Dummer Academy. In the Newbury-Rowley area this member is cut out by a fault west of Ellsworth road, but it reappears again to the southwest in the Topsfield-Middleton area.

This member overlies conformably the Lower Rhyolite and is overlain conformably by the Upper Rhyolite. The Andesite shows many facies changes, great variation in thickness, and intercalations of sediments. On the island north of Ox Pasture Hill, McCarthy (1958) subdivided the Andesite into an upper porphyritic flow, an upper tuff horizon, and a lower tuff horizon.

Besides relatively thin lenses of slate and conglomerate which appear 3,500 feet above the base of the Andesite on the northeast, a thin bed of fossiliferous calcareous shale intercalated in this volcanic unit was found by Keith at Glen Mills, in 1915. Toulmin (1958) reported from the Topsfield-Middleton area the presence in the Andesite of "gray to green, evenly and thinly bedded feldspathic siltstones and fine grained sandstones, possibly in part of pyroclastic origin", with "at least one very thin bed of impure, gray, ostracod bearing limestone". The thin bedded ostracod bearing limestone referred to by Toulmin crops out just west of the Old Coppermine road (see plate 4). Fossils collected in this locality were, in 1918, according to Foerste (1920, pp 206-207), "submitted to Dr. R.S. Bassler, of the Nited States National Museum, and identified by him as belonging to the Leperditia alta group, thus suggesting the presence of strata of Cayugan or Upper Silurian age."

The porphyritic andesites are greenish gray to dark gray flows with highly amygdaloidal bands. The amygdules are filled with epidote, calcite and/or chlorite. Sometimes the walls of the amygdules are covered by a layer of chlorite and then filled with calcite. The phenocrysts are plagioclase (15%) and orthoclase (5%). The rock has abundant veinlets of epidote.

Microscopic fabric of the porphyritic andesite:- Plagioclase and orthoclase phenocrysts in an amorphous to microcrystalline groundmass showing faint extinction due to advanced alteration. Epidote occurs in veinlets and also as a yellowish green aggregate replacing lime-magnesian or ferro-magnesian minerals formerly present. The alteration to saussurite, chlorite, carbonate and sericite is so far advanced as to make it impossible to estimate the original composition of the rock. Sometimes phenocrysts with outline of an amphibole are found completely replaced by chlorite, calcite and hematite. In places the opaque content of the rock is very high, about 12%. Quartz is present along numerous veinlets.

Important rock forming minerals present in the porphyritic andesite are oligoclase and orthoclase. Secondary minerals are calcite, chlorite, saussurite, sericite, hematite, magnetite, ilmenite, pyrite, leucoxene and limonite (See appendix No. 4, 5, 6 and 14).

The tuffaceous facies of the Andesite is usually a mottled dark purplish brown and green, porphyritic rock. The phenocrysts are orthoclase (6%) up to 2.5 mm long and laths of plagioclase (8%) up to 2 mm long. Rock fragments of the same nature as the groundmass make up about 40% of these tuffs. The rock show patches of green chloritic alterations. It weathers to a yellowish brown color.

Microscopic fabric of the tuffaceous andesite:- Ferruginous rock, formed by phenocrysts of plagioclase and orthoclase in an amorphous to cryptocrystalline groundmass. The orthoclase as well as the plagioclase is deeply altered. The products of alteration are sericite, carbonates and chlorite. The foreign fragments in the rock have essentially the same composition as the host rock but show better crystallized groundmass with microlites of plagioclase and are much less ferruginous. The over-all rock however contains a considerable amount of disseminated iron and titanium oxides which make it almost completely opaque in places.

Besides albite and orthoclase the rock contains calcite, chlorite, sericite, hematite, magnetite, ilmenite, leucoxene, and limonite (See appendix No. 13).

The slate and conglomerate intercalated in the Andesite are slightly metamorphosed water deposited volcanic ash and tuffaceous material. The cleavage is in general well developed. The slate is purple to purplish brown, irregularly bedded containning fragments of volcanics. The well developed foliation allows deep weathering. The weathered surface is yellowish green along the foliation planes and dark green on the outer surface. The conglomerate is mottled red, pink, brown and gray, with the pebbles forming about 80% of the rock and the matrix about 20%. Pebbles of rhyolite and andesite up to 2 inches in diameter are the main constituents. On the northeast, the slate and conglomerate appear 3,500 feet above the base of the Andesite and extend for more than one mile with minor variations in thickness (about 100 feet) through most of their extension; toward the northeastern end they thicken to about 300 feet. At the Mill river bridge they are exposed for a short distance. To the southwest, between Topsfield and Middleton the slate and conglomerate crop out again along the Blue Star Memorial Highway.

Microscopic fabric of the slate and conglomerate:- They are almost opaque due to disseminated iron oxides; however, volcanic fragments varying in size from microscopic to several mm in diameter show good transparency. Albite and orthoclase are the most abundant minerals in the lithic fragments. Some fragments are much altered to chlorite, carbonates, epidote and limonite. Chloritization is well developed along the foliation surfaces.

Minerals identified under the microscopic are orthoclase albite, quartz, epidote, chlorite, calcite, hematite, ilmenite, leucoxene and limonite. About 50% of the rock, however, is formed by an indistinct groundmass (See appendix No. 7).

Upper Rhyolite member

The type section of the Upper Rhyolite is here designated as the exposures along the Newburyport Turnpike, just east of the Old Newbury Golf Club. This member reaches its greatest thickness (2,200 feet) on the northeasternmost part of the belt, where it appears as a bedrock ridge. To the southwest its thickness decreases slightly, the ridges become less prominent and finally it disappears being cut out by a fault just east of Daniel road. This member is not found elsewhere in the Newbury-Rowley area or in the Topsfield-Middleton area, due to faulting.

The Upper Rhyolite is formed by pinkish to brick red, purplish and greenish gray to light green banded and locally porphyritic rhyolite flows, tuffs and agglomerates. These rhyolites are generally tough rocks breaking with sharp edges. Banding and tuffaceous beds are sometimes useful for bedding determination. The rocks are shattered in places and transversed by numerous small faults, sometimes microscopic, with the fractures filled with quartz (See figure 3); frequently slickensided surfaces are exposed.

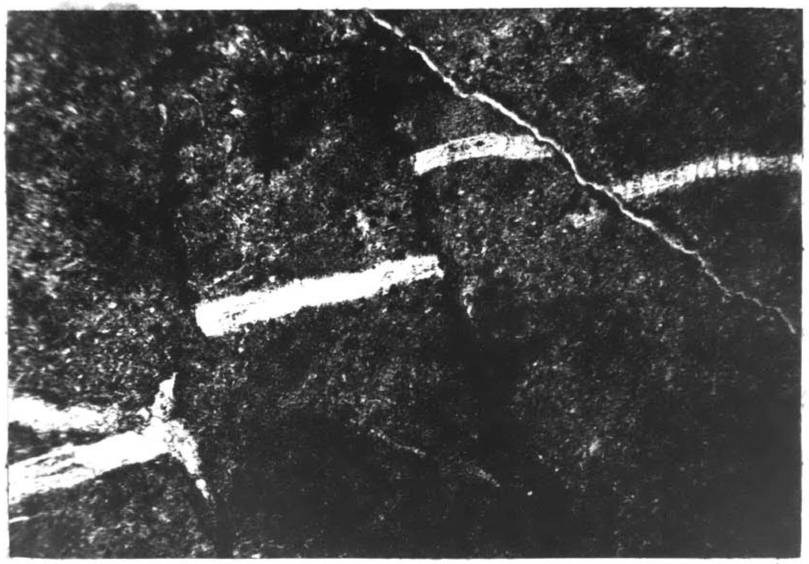

Fig 3.- Microscopic faults in the Upper Rhyolite. X45

The lighter facies of the Upper Rhyolite weathers to a pinkish yellow color; after the removal of the kaolinitic material of the weathered zone, a thin veneer of quartz remains. The weathered surface of the brick red rhyolite is of a yellowish brown color.

At the base of the Upper Rhyolite a bed of rhyolite breccia is exposed on the northern side of the bridge over the Mill river, west of the Newburyport Turnpike. The breccia is formed by varycolored constituents well cemented by a grayish green rhyolitic matrix. The constituents, which form about 80% of the rock, are gray, green, red, brown and white rhyolite fragments. The green matrix, which makes up 20% of the rock, is also formed by rhyolitic material.

Microscopic fabric:- In thin section the mottled rhyolite from near the Old Newbury Gulf Club shows that the quartz present is mostly as fracture filling. The orthoclase and plagioclase appearing in the cryptocrystalline rock mass have been largely altered to sericite and carbonates. The rock shows two sets of fractures filled with quartz; one set is very well developed with the fractures perfectly parallel; the other set is not so well developed. The major rock forming minerals present are quartz, orthoclase and albite. Secondary minerals are calcite, sericite, hematite (traces), limonite (in veins), and leucoxene (trace). 40% of the rock is amorphous (See appendix No. 9).

Fig 4.- Upper Rhyolite texture. Crossed Nichols. X 45.

The brick red felsite in thin section shows fine grained hematite disseminated all through the rock. In places the amount of hematite is enough to make the rock almost opaque. With the exception of the veinlets where the crystals of quartz, albite and orthoclase are well developed, the rock shows an amorphous to cryptocrystalline texture. Sometimes the hematite is concentrated in small patchy masses.

Quartz, albite and orthoclase are the major minerals, followed by hematite. Carbonates and leucoxene appear as alteration products. The amorphous and indistinctly crystallized fraction of the rock reaches about 64% (See appendix No. 10).

The rhyolite breccia from the Mill river bridge shows under the microscopic some rhyolite fragments with orthoclase crystals and plagioclase laths as phenocrysts in a microcrystalline groundmass of quartz, orthoclase and albite; orthoclase phenocrysts show overgrowth rims and incipient alteration to sericite. Other fragments contain epidote and chlorite as alteration products of former ferromagnesian minerals. Still other have a considerable amount of hematite and leucoxene. The matrix of the breccia contains some phenocrysts of orthoclase quartz and plagioclase in a cryptocrystalline groundmass, which is much altered to sericite and carbonates.

The minerals present are quartz, orthoclase, albite, calcite, sericite, hematite, limonite, ilmenite, leucoxene and magnetite. The rock has about 36% of amorphous material (See appendix No. 8).

Distinction between the Lower Rhyolite and Upper Rhyolite:-

The Lower Rhyolite is more uniform in color and texture, horizontally as well as vertically, in the section; microcrystalline texture is more regularly developed and it shows typical myrmekitic structures. The color of this member is duller as compared with the bright, varicolored Upper Rhyolite.

The Upper Rhyolite has marked changes in color, texture and, to a certain extent, in composition, horizontally as well as vertically. The rock is typically cryptocrystalline not showing myrmekitic structure.

Basalt member

The type section of the Basalt is here designated as the exposures on both sides of the Newburyport Turnpike, just south of Parker river, where this member of the volcanics forms ridges parallel to the rhyolitic ridges. It reaches a thickness of about 3,000 feet east of Newbury Old Town, but becomes thinner to the southwest and it is finally cut out by a fault SW of Governor Dummer Academy. As happens with the Upper Rhyolite, no outcrops of the Basalt are found to the southwest.

The base of the Basalt unit is formed by a massive, black, fine grained flow, which immediatly overlies conformably the Upper Rhyolite; above that there is a bed of quartz pebbles in a siliceous matrix, which is covered by a black slaty tuff. These three beds make a very good marker horizon, but unfortunately they crop out for only 3/4 of a mile.

Because it dips steeply to the northwest against the basement complex, the Basalt is inferred to be in fault contact with the rocks of the basement.

West of Newburyport Turnpike, the Basalt occurs as amygdaloidal flows, tuffs and mudstones. To the east of the turnpike, porphyritic flows or tuffs form a prominent ridge line which continues for one mile.

Most of the Basalt is a dark greenish-gray to dark gray, very fine grained rock formed mostly of plagioclase, epidote and chlorite. Bands of segregated epidote are common. Amygdules of calcite and fine veinlets of epidote are abundant. Locally the predominance of epidote gives the rock a pistachio green color. The bedding in the Basalt is marked by a great number of flows, sometimes showing amygdaloidal structures between them. The flows vary in thickness from a few inches up to tens of feet. The thickest flows have in places an over-all massive appearance. The weathered surface of this member is very dark gray to black.

The Basalt does not occur between a northwest striking fault that cuts the volcanic belt just west of Newbury Old Town and another fault striking approximately N 5 E passing through Kent's Island.

Microscopic fabric:- The specimens show almost complete alteration. Any ferro-magnesian mineral originally present in the rock has been altered to saussurite, chlorite and carbonates. The calcic fraction of the plagioclase is so altered as to render it difficult to determine the original composition of the species; the present composition is that of oligoclase but it may have been labradorite in the original rock. The texture of the rock is however preserved. It varies from a cryptocrystalline to a microcrystalline texture showing plagioclase microlites. Quartz is present in veinl ets. Some veinlets have the walls covered by a thin layer of epidote and are filled with calcite.

The minerals present in the rock are oligoclase, quartz (in veinlets), saussurite, chlorite, carbonates, magnetite, ilmenite and leucoxene. Indistinctly crystallized material forms about 20 to 50% of the rock (See appendix No. 11 and 12).

As with the Andesite the name Basalt is used here for stratigraphical purposes only since alteration makes it impossible to determine the original mineralogy of the rock. The designation of greestone could be more properly used for the rock.

BASEMENT COMPLEX

The Newbury volcanic belt is surrounded by a complex of older igneous rocks which, for our purpose is called basement complex. Those igneous rocks include the Dedham granodiorite-granite and the Newburyport quartz diorite.

Dedham granodiorite and granite:- The true granodiorite phase of this unit is a light gray to dark greenish gray, coarse to very coarse grained rock formed mostly of plagioclase, microcline, quartz, biotite and minor chlorite. In places, however, there is a definite predominance of microcline over plagioclase. This phase, which shows a distinctly reddish color, is more correctly called a granitic phase of the Deham granodiorite.

Newburyport quartz-diorite:- This rock is a light gray, medium grained, granular rock containning orthoclase, labradorite, augite, hornblende and quartz with chlorite, uralite and epidote as decomposition products. Emerson (1917 p. 178) stated that the Newburyport quartz-diorite in places merges into the Dedham granodiorite.

AGE AND CORRELATION

Newbury-Rowley area:- Emerson (1917 p. 163) writes about the fossils of Glen Mills: "Just at the base of the mud flow, immediatly overlying the lava and surrounding the detached block, is a few inches of calcareous shale in which abundant fossils were discovered by Mr. Keith in August, 1915. A collection has since been made by R. D. Mesler, of the United States Geological Survey, and the fossils have been examined in a preliminary way by E. O. Ulrich. They are all of marine types and comprise one or more species of brachiopods, a species of gastropod, fragments of crinoids, and probably a pelecypod."

"The fossils have not been studied in detail and only one species has so far been identified, but according to Mr. Ulrich the fauna appears to be similar in a general way to that of the Chapman sandstone of northeastern Maine, which he regards as of Oriskany age. The fauna at Rowley may, however, according to Mr. Ulrich, be somewhat older and more nearly contemporaneous with the Pembroke and Eastport formations of the Eastport region, which has been classed as Cayugan. The age of the Newbury complex, therefore, is not definitely determined, but it appears to be either late Silurian or early Devonian".

Cloud (oral communication to C. Schneer, 1949) found similarity of the Glen Mills fossils with Camerotoechia leightoni (Williams), from the Pembroke formation at Leighton Cove, Maine. He concludes that the beds in question are either Silurian or Devonian and "that they may be correlative with the Pembroke formation, regarded of Upper Silurian age".

In 1960 Professor Arthur J. Boucot, in a writen communication states: "The fossil bed at Glen Mills has yieldded abundant specimens of a rhynchonellid and a high-spired gastropod. The gastropod is a lophospiroid, which is of little aid in dating the beds. The rhynchonellid has short dental lamellae in the pedicle valve on either side of a weakly impressed muscle field. The brachial valve of the rhynchonellid is characterized by a median septum, which supports a cruralium flanked laterally by uncrenulated dental sockets. The rhynchonellid has about three plications on the fold and in the sulcus, and another three or four on each flank. Rhynchonellids of this type are commonly assigned to Camarotoechia, but the lack of crenulated dental sockets makes this assignment untenable. "Rhynchonella" nucula of the British Ludlovian is very similar as are shell of Silurian, probably Ludlovian age, near Eastport, Maine. Until more is known about Silurian and Gedinnian rhynchonellids it probably is best to conclude that the Glen Mills fossil bed is of Silurian or Gedinnian age, (true Camarotoechia ranges down into the Oriskany and its equivalents whereas the "R." nucula type does not appear to range above the Gedinnian) with a Ludlovian age favored. Ulrich (Emerson, 1917, p. 163) previously concluded, on the basis of ostrocods, that the Glen Mills beds were of Lower Devonian age, but his evidence sounds sketchy, although it cannot be completely dismissed at this time."

Middleton-Topsfield area:- Foerste (1920, p. 206-207) referring to fossils found in the area between Middleton and Topsfield, west of the Old Coppermine road writes: "In 1918 the best specimens were submitted to Dr. R. S. Bassler, of the United States National Museum, and identified by him as belonging to the Leperditia alta group, thus suggesting the presence of strata of Cayugan or Upper Silurian age."

In 1957 a material collected in the same area was submitted to J. M. Berdan of the Paleontology and Stratigraphy Branch of the U.S.G.S. in Washington. In her report issued in 1/27/58 about the fossils she states: "The collection contains Leperditia sp. and small ostracodes which are too poorly preserved to identify. The leperditiids are not well preserved, but two or three specimens show traces of the eye tubercle, chevron-shaped muscle scar and round adductor muscle scar characteristic of the genus. It is not possible to be sure whether these specimens belong to Leperditia (Leperditia), or Leperditia (Herrmannina) because of the poor preservation, nor is it possible to identify them as to species. Swartz (Jour. Paleont. V. 23, no. 3, pp. 319-320, 1949) described the genus Chevroleperditia, which is distinguished from Leperditia (Herrmannina) only by lacking a taxodont hinge structure in the material at hand, there is a remote possibility that it might belong to Chevroleperditia. However, this is considered improbable, as the only known species of Chevroleperditia, C. chevronalis, has a rather subdued adductor muscle scar, whereas the Massachusetts specimens have a well developed adductor scar.

The range of leperditiids having both a chevron-shaped scar and an adductor scar is Upper Ordovician to Middle Devonian, but in the known Upper Ordovician species the chevron-shaped scar is weakly developed, and would not leave as marked a trace as is present in these specimens. The age of this collection, therefore, may be considered to be Silurian or Devonian, probably Upper Silurian or Lower Devonian, based on the distribution of leperditiids in the Appalachian region."

The paleontological work therefore show that the volcanics of both the Newbury-Rowley and Topsfield-Middleton areas are either Upper Silurian or Lower Devonian with the Upper Silurian age favored. The paleontological evidence is strongly supported by structural and stratigraphical correlation. Therefore there is no doubt that the volcanics of the Topsfield-Middleton area are a southwestward extension of the Newbury volcanics.

<u>Correlation with the Lynn and Mattapan volcanics</u>:- In 1880 Crosby (p.63) noticed the similarity of the rocks of the Newbury area with the volcanics of the Boston area. About the volcanics from Marblehead Neck he wrote: "There are several distinct varieties of petrosilex on Marblehead Neck. The most conspicuous and beautiful of this is the banded variety already alluded to. This has substantially the same characters as in Newbury". Further (P. 85, bottom) when referring to the volcanics of the Neponset Valley which belong to the Mattapan volcanics he stated: "As already observed, the structure of these striped rocks in Hyde Park is substantially a repetition of that studied on Marblehead Neck and at other points".

Sears (1905 p. 222) included the Newbury and

Lynn volcanics under the general head of "Igneous Volcanic Rocks" and wrote: "These rocks are easely separated int into two great groups, the acid and the basic volcanics. The acid volcanics occur in massive forms. Exposures may be seen on Marblehead Neck, at Swampscott, Lynn, and Saugus, and from there extending into Middlesex County. These rocks also extend easterly into the bay by island and ledges. Another area appears at Rowley and Newbury in the form of a long and comparatively narrow mass not over one mile in width, extending in a northeasterly direction from Batchelder's brook, at Clay lane, Rowley, across Rowley and Newbury to the tidal marsh beyond Pine island".

In 1917 Emerson (p. 163-164), based on the identification by Ulrich of the fossils found by Keith at Glen Mills in 1915, considered the Newbury volcanics as older (Silurian or Devonian) than the Lynn and Mattapan volcanics mapped by him as Mattapan Volcanic Complex which he considered as Carboniferous. The Carboniferous age for the rocks of the Lynn and Mattapan areas was based in the assumption that they were correlatable with the volcanics of the Narragansett basin which are intercalated in the Carboniferous Wamsutta formation. However the structural relation, geographical distribution and field appearance would rather point a closer relation of the Lynn and Mattapan rocks with the Newbury volcanics than with those volcanics of the Narragansett basin.

Clapp (1921 p. 30) included the Newbury, Lynn and Mattapan volcanics under the general name of Lynn Volcanics: "Two areas of effusive volcanic rocks occur in Essex County; one in the southern part, the typical area of the Lynn volcanics, extends westward from Lynn to Middlesex County; and the other, in the northern part, underlies the lower portion of the Parker River basin and extends southward nearly to Topsfield. The northern area was mapped as Newbury Volcanic Complex by Emerson, who regards the rocks as older than the typical Lynn volcanics." "The volcanic rocks of the two areas are similar and were undoubtedly erupted during the same period. They are therefore assigned by the writer to the same formation and called Lynn Volcanics."

La Forge (1932 p.29) again considered the volcanics in question under separate names of Newbury, Lynn and Mattapan volcanics but considered them as of probable equivalent age when he wrote: "The age of the rocks of the volcanic complex forming the Newbury Basin, in Essex County (Newbury Volcanic Complex), was determined as probably Lower Devonian through the discovery by Keith, in 1915, of marine fossils regarded by Ulrich as probably of that age, in a calcareous shale that is an essential part of the complex. The rocks of the Lynn complex are essentially identical lithologically with those of the Newbury Basin and are believed to be of the same age. That the rocks of the Mattapan complex are also of that age seems fairly certain for similar reasons."

In 1948 Bell mapped the Lynn and Mattapan volcanics also separately but of probably the same age as the Newbury volcanics. Writing about the Lynn volcanics (p. 230) he stated: "Somewhat similar volcanic rocks are found approximately fifteen miles north of the Lynn area in the

Newbury basin." "If the Lynn volcanics can be properly correlated with those of the Newbury basin a Lower Devonian a age for all of these rocks is indicated." About the Mattapan volcanics (p. 242) he wrote: "The age of the Mattapan Volcanic Complex is presumed to be essentially the same as that of the Lynn Volcanics since the basal flows of both formations were erupted upon an identical kind of terrain." "On the basis of field relations a Lower Devonian Age such is possible for the Lynn and Newbury volcanics seems to be a reasonable estimate for the age of the Mattapan Complex."

As seen above there is a general agrement among geologists regarding the possible correlation of the Newbury volcanics with the Lynn and Mattapan volcanics. The field appearance, mineralogy, degree of alteration, litho logic types, and chemical similarity of those rocks leave little doubt that they belong to the same volcanic cycle. The fact that the Newbury volcanics are now found to extend to the southwest toward the general area where the volcanics of the Boston area occur is another clue that they may belong to the same sequence. A direct connection between the volcanics in question is dependant upon detailed field work done mainly through the east and southeast parts of the Reading quadrangle. Professor Brace, of M.I.T., reports (oral communication, 1960) occurrence of the Andesite member of the Newbury volcanics in an outcrop about 2 miles southwest of the Topsfield-Middleton strip. This outcrop shown on plate 6 is on the continuation of the southwestward trend of the Newbury volcanics.

The Lynn and Mattapan volcanics have a close megascopic similarity with the Newbury volcanics, including felsites, bright colored rhyolites, and intercalations of more basic members. The mineralogy is essentially the same with probably slight variations that are bound to happen within the same volcanic unit from place to place. The stage of alteration described by Bascom (1900 p. 126) and (1912 pp. 141-157) of the Mattapan volcanics of the Nepponset Valley is exactly the same as that found in the Newbury volcanics. The alternations of light acidic rocks of rhyolite composition with rocks of andesitic composition bears a close similarity with the facts observed with the Newbury volcanics.

A chemical analysis published by Crosby (1880 p. 58) of samples taken from the Bartlett Mine, South of Parker river on the Lower Rhyolite belt of the Newbury volcanics shows comparable chemical composition with the rhyolites of the Lynn and Mattapan volcanics as shown in the following table:

	I Bartlett Mine (Newbury volc)	II Rhyolite Dike (Mattapan volc)	III Marblehead Neck (Lynn volc)
SiO_2	77.200	73.72	70.64
Al_2O_3	12.482	13.22	15.34
Fe_2O_3	1.57	1.48	1.83
FeO	-	1.72	1.10
MgO	-	.66	.52
CaO	.80	.65	1.24
Na_2O	4.423	4.52	5.23
K_2O	1.230	2.90	3.55
H_2O +	2.004	.36	.14
H_2O -		.10	.38
CO	-	.15	-
TiO	-	.34	.90
MnO	trace	trace	trace
Total	99.709	99.82	100.87

I. E. W. Walton, analyst (Crosby, 1880 p. 58)
II. Wm. T. Hall, analyst (Bascom, 1912 p. 148)
III. H. S. Washington, analyst (Sears, 1905 p. 404)

With minor variations that are to be expected within the same lithologic unit, the results are comparable, the most striking similarity being the high soda content of the rocks involved, which makes them soda-rhyolites.

It is possible that some of the extrusives, mapped as Woburn and Marlboro formations by previous workers, belong to the Newbury volcanic sequence. The Woburn formation is approximately on the southwest continuation of the strike of the Newbury belt and dips steeply northwestward as do the Newbury volcanics (see plate 6). The Woburn formation is described by Bell (1948, p.33) as being "entirely of volcanic origin since the numerous outcrops examined and several specimens collected for microscopic study are all definitely igneous types. They are stratified, or layered, showing a uniform northeast-southwest strike and steep northwestward dip." "Light colored whitish or pinkish phase seem to be predominant in the lower flows exposed and gray, greenish or black phases in the uppermost. Some outcrops show alternating light and dark colored strata varying from a foot to several feet in thickness."

The Woburn formation, however, is much more metamorphosed and distorted than the typical Newbury volcanics and if it is equivalent, the rocks of Woburn have been subjected to more intensive local metamorphism.

The rocks of the Marlboro formation, in the area mapped by Bell to the north of Boston, are very heterogeneous in origin and lithology, but part of the formation is made up by extrusives rocks. Bell (1948 p.21) mentioned that "much of this group is undoubtedly sedimentary as indicated by the presence of thick limestone beds specially in the Rhode Island and southern Massachusetts sections. In other localities the group appears to consist mainly of basaltic lavas."

In the Mystic Lake area and southwestward between Arlington and Belmont, the rocks of the Marlboro formation are highly metamorphosed and coarse grained with no apparent relation to volcanic origin. With exception of these areas on the southwest end of the belt, the North Saugus section, and the west side of the south Reservoir of Winchester Water Works, Bell stated that the "l arge southeastward belt mapped as Marlboro Formation is believed to consist entirely of basaltic lavas. Several variations are represented, some of which have similar megascopic appearance to one another and also closely resemble the highly chloritic schists. This feature makes field identification of weathered outcrops somewhat risky, but since se veral representative specimens collected for microscopic study were all volcanic types it is reasonably certain that any sedimentary strata that may exist must be quite thin.

A type characteristic of some of the small isolated outcrops in Lynn, North Saugus and along the southeast edge of the main belt in Wakefield is a very fine grained, even textured, even colored, dark gray rock. The grain is so fine that it is almost impossible to detect crystalline texture, even with a hand lens. Microscopic examination shows a pilotaxitic texture with a mineralogical composition consisting almost wholly of closely packed minute pla gioclase laths and needles. Some specimens have minute lath-shaped plagioclase phenocrysts. The mineral is usually labradorite, but in some cases is andesine. The small amount of interstitial material when it can be identified under the microscope consists of the alteration minerals chlorite, calcite and epidote accompanied by un abundant extremely fine grained opaque mineral assumed to be magnetite."

"Amygdaloidal texture is most often found in flows that are otherwise pilotaxitic. A variety of secondary minerals now form the amygdules. Good exposures of these flows are found on the north slope of the hill called High Rock near Wakefield-Melrose town line."

These volcanics of the Marlboro formation could possible be correlated with the more mafic members of the Newbury volcanics. This is more evident when it is noticed that the Marlboro formation forms a continuous belt with the Lynn volcanics, as shown on plate 6.

Detailed work has to be done in order to stratigraphically subdivide the volcanics of the Woburn and Marlboro formations and try to work out the relation between them as well as to find out the relation they bear to the Newbury-Lynn-Mattapan volcanics.

Emerson (1917 pp. 200-201) considered the rocks of the Lynn and Mattapan volcanics as equivalent in age to the volcanics intercalated in the Carboniferous Wamsutta formation of the Narragansett basin, near North Attleboro. As the Newbury volcanics are correlatable with the rocks of Lynn and Mattapan, as shown above and they are of probable Upper Silurian age they are considered here as belonging to a volcanic cycle older than the volcanics of the North Attleboro area (See plate 7).

S T R U C T U R E

The Newbury volcanics crop out in a belt in northeast Massachusetts which tends to narrow from the northeast to southwest. This belt which has a general N 65 E strike on the northern portion, from the mouth of the Island river to the Governor Dummer Academy, and bends sharply to a general N 25 E direction along a line connecting Ox Pasture Hill and Governor Dummer Academy.

The over-all structure of the area is inferred to be a homocline with all formation dipping northwestward. The conclusion is drawn from both stratigraphic and structural evidence. No southerly dipping beds were found. The top and bottom evidence all suggests tops to the northwest. The upward gradation of amygdaloidal structures from the junction of Little river and Parker river, and on the south bank of the Parker river marsh west of route 1A show that the beds are rightside up. Some cleavage surfaces found in the conglomerate at the junction of the Mill and Parker river show tops to the north and the beds rightside up. No indications of overturned beds were found.

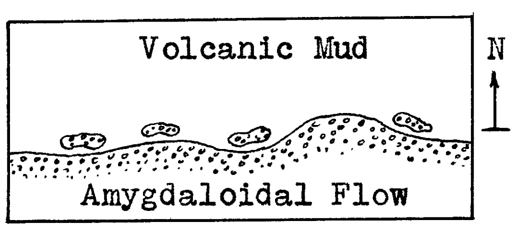

Fig. 5 Amygdaloidal Structure

Scale: 1" = 1'

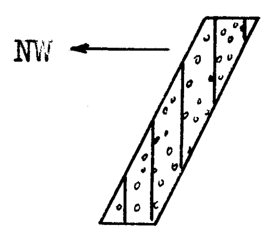

Fig. 6 Cleavage

Scale: 1" = 1'

The structural relationship of the volcanics with the surrounding basement complex is not very clear.

No outcrop of the contact between the volcanics and the basement rocks was found on either side of the belt. However the evidence indicates a fault contact on the northwest while the contact on the southeast may be a non-conformity.

The evidence for a fault on the northwest is that all the volcanic members are dipping against the contact surface. Also the sudden elimination or truncation of some of the members shows that the northwest contact must be a fault. This is more evident on the western portion of the belt from Governor Dummer Academy as far as Linebrook where a series of faults eliminate step by step all volcanic members.

The volcanic belt is cut transversely by three wrench faults. Along those faults only the horizontal displacement has been inferred since no outcrop of either fault surface was found allowing the calculation of the vertical displacement, if any has occurred.

One of the transverse faults occurs just east of Newbury Old Town. It strikes N 30 W and has a horizontal slip of about 2,900 feet. This fault is inferred by the outcrop pattern on the map where the Upper Rhyolite strikes into the Andesite. The eastern block has moved south relative to the western block. Due to the scarcity of outcrops to the southeast it is impossible to see how far south the fault extends.

The second major displacement is inferred on the western part of Kent's Island. Here the Basalt seems to strike into the Upper Rhyolite. This fault, which strikes approximately N 5 E, has a horizontal slip of 1,300 feet. McCarthy (1958), who has studied this area, concluded that this fault apparently dies out to the south because the lower part of the Andesite and the Lower Rhyolite are not displaced by it (See plate 2).

Toward the south, after the rotation of the strike of the volcanic members from N 65 E to N 25 E, a third fault is inferred approximately along the Weatherfield road. This fault, which has a N 80 E strike and a 600 feet horizontal slip, is inferred on the ground that here the continuity of the Lower Rhyolite is partly broken against the basement complex. In addition the Upper Rhyolite strikes into the basement along this fault.

The last outcrop of the Lower Rhyolite in the Newbury-Rowley area is located 4,000 feet south of Linebrook. Any attempt to connect the Lower Rhyolite and the Andesite of this area with those formations identified in the area mapped by Toulmin between Topsfield and Middleton was bound to fail due to the lack of outcrops in the interval between the two areas.

Although the general orientation of the volcanics in the Linebrook area is similar to that of the Topsfield-Middleton area, they must have been offset by a fault or a set of faults because the extension of either one would fall slightly off the continuation of the other one.

Three cross sections of the volcanics were drawn: the first, in the northeastern end, cuts one of the wrench faults; a second section was drawn across the belt where the strike of the volcanics bends to the south and shows a complete section; a third cross section was taken in the southeastern end where only the Lower Rhyolite and the Andesite are still present.

CONCLUSIONS

The newbury volcanic belt is formed by a northeast striking homocline dipping steeply to the northwest. The volcanic section is formed by four members: Lower Rhyolite, Andesite, Upper Rhyolite, and Basalt.

The more mafic members of the series are so altered to greenstones as to prevent the exact determination of the original mineralogy of the rocks. So the designations of Andesite and Basalt are used more for stratigraphical purposes.

The age of the volcanics, as based on fossils found at Glen Mills and in one outcrop just west of the Old Coppermine road, is placed between Upper Silurian and Lower Devonian with the Upper Silurian age favored.

The Newbury volcanics formerly reported only from the Newbury-Rowley area are found now to extend southwestward 17 miles toward Boston. This reinforces the assumption that the volcanics in question are correlatable with the Lynn and Mattapan volcanics of the Boston area. Moreover the field appearance, mineralogy, lithologic types, degree of alteration and bulk chemical composition are comparable, thus making the correlation more evident.

Part of the Woburn formation as well as the dark volcanic rocks assigned by previous workers (Emerson 1917, p. 28, La Forge 1932, p. 17, Bell 1948, p. 21) to the Marlboro formation may belong to the same volcanic array and are here tentatively reassigned to the Newbury volcanics until more detailed work in the space between them can clarify their relations.

The volcanics of the North Attleboro area are intercalated with the Carboniferous Wamsutta formation (Coomaraswamy 1954, p. 8-12) and are, therefore younger than the Newbury, Lynn and Mattapan volcanics.

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APPENDIX

Petrographic Description of 14 thin sections of the Newbury Volcanics whose numbers appear on the maps.

1. Hand specimen description: - Dark brown to purplish, flinty, porphyritic rhyolite showing phenocrysts of quartz (15%) and sanidine (10%) in an aphanitic groundmass. Due to intensive fracturing the weathering alteration has penetrated deep in the rock so as to render it difficult to get a fresh sample. Rare well developed crystals of pyrite. The rock is dotted by very dark green chloritic alterations. Limonitic alterations give the weathered surface of the rock a dull yellowish brown color.

   Microscopic fabric: - Porphyritic texture with phenocrysts of quartz and sanidine immersed in a microcrystalline groundmass. Well developed myrmekitic structure. Some phenocrysts of quartz are surrounded by a layer of microcrystalline quartz; the quartz grains of these layers have parallel extinction with the phenocrysts (recrystallization). The phenocrysts of orthoclase are, as a rule, elongated crystals. Limonite originated from alteration of pyrite and hematite is disseminated between grains and in veinlets along fractures. Along the fractures the heavily limonitic zone is 1 to 2 mm deep.

Mineralogy: -

Transparents		Opaques	
Quartz	40%	Hematite	4%
Sanidine	32%	Limonite	3%
Albite	10%	Pyrite	1%
Microperthite	6%		
Chlorite	4%		

Stratigraphic unit: - Lower Rhyolite member

2. Hand Specimen description: - Light pinkish brown, highly siliceous, aphanitic rhyolite. Abundant quartz (20%) and sanidine (15%) as phenocrysts. The rock is cut by intermittent quartz veinlets. The weathered zone is a very light pink kaolinitic layer; where this layer is partly removed patches of quartz are prominent.

Microscopic fabric: - Microcrystalline, equigranular, merocrystalline, hypiodiomorphic-granular texture. Well developed myrmekitic structure.

X-ray powder picture shows absolute predominancy of quartz and feldspars.

Mineralogy: -

Transparents		Opaques	
Quartz	45%	Hematite	2%
Sanidine	34%	Limonite	1%
Albite	12%		
Microperthite	5%		
Carbonates	1%		
Sphene	tr		
Sericite	tr		

Stratigraphic unit: - Lower Rhyolite member

3. Hand specimen description: - Brown porphyritic rhyolite with phenocrysts of sanidine (6%), quartz (1%), and lathes of plagioclase (1%) in an aphanitic groundmass. The weathered zone is formed by a layer of about 2 mm thick of a whitish brown kaolinitic material. On the fresh surface of the rock chloritie alterations of former ferromagnesian minerals dot the rock with green patches.

Microscopic fabric: - Phenocrysts of quartz, albite and sanidine immersed in a cryptocrystalline to microcrystalline groundmass. Ferromagnesian minerals have been altered to chlorite, saussurite, and calcite. Phenocrysts of albite and sanidine have been partly replaced chlorite and carbonates. Flow structures are conspicuous by alignment of grains and drag around phenocrysts.

X-ray powder picture very similar to 2 with quartz and feldspars dominant.

Mineralogy: -

Transparents		Opaques	
Sanidine	42%	Leucoxene	2%
Quartz	35%	Limonite	tr
Albite	15%	Hematite	tr
Chlorite	3%	Ilmenite	tr
Saussurite	2%	Magnetite	tr
Carbonates	1%		

Stratigraphic unit: - Lower Rhyolite member

4. Hand specimen description: - Light gray, aphanitic, brittle rock, breaking in very sharp edges. The rock is

thoroughly fractured allowing a deep weathering penetration. It weathers externally to a grayish pink color.

The weathered surface along the fracture is of a greenish gray color.

Microscopic fabric: - with exception of few, ill defined, small phenocrysts the rock is amorphous to cryptocrystalline. Numerous veinlets of quartz. Microscopic veinlets of limonite and epidote are also present. Some of the veinlets are filled by quartz and epidote or limonite and epidote.

X-ray powder picture show only quartz probably from the veinlets where the quartz was well crystallized.

Mineralogy: -	Transparents		Opaques
	Quartz (veins)	12%	Limonite 2%
	Feldspar	8%	
	Carbonates	5%	
	Epidote	2%	
	Sericite	1%	
	Amorphous to cryptocrystalline	70%	

Stratigraphic unit: - Andesite member

5. Hand specimen description: - Greenish gray to gray, amygdaloidal, porphyritic rock. Amygdules filled with calcite and chlorite. On the weathered surface calcite is readily removed in solution leaving an external vesicular appearance. The weathered surface is dark gray. Abundant veinlets of epidote.

Microscopic fabric: - Microcrystalline, porphyritic texture. Phenocrysts of oligoclase form about 5% of the rock. The microlites of plagioclase of the groundmass shows faint extinction due to the advanced stage of alteration. The ferromagnesian minerals have been completely altered. The original composition of the plagioclase is difficult to estimate because its more calcic fraction has been very much altered leaving only a cloudy mass of the more sodic fraction. The amygdules are formed in general by a layer of chlorite enclosing a large nucleus of calcite.

Mineralogy: -

Transparents		Opaques	
Oligoclase	40%	Hematite	2%
Calcite (mostly in amygdules)	22%	Limonite	2%
Chlorite	25%	Ilmenite	1%
Epidote	5%	Leucoxene	3%

Stratigraphic unit: - Andesite member

6. Hand specimen description: - Very dark brown aphanitic rock with greenish gray patches and cut by randomly oriented veinlets. The weathered surface is yellowish green to grayish green.

Microscopic fabric: - Microscopically porphyritic rock with small phenocrysts of quartz in a cryptocrystalline to microcrystalline groundmass. Very high in opaque content. Ferromagnesian minerals are altered to a mixture of chlorite, epidote, and hematite; chlorite stains the rock around the place initially occupied by the ferromagnisian minerals fainting outward from the center. Veinlets of quartz and calcite are very abundant.

X-ray powder picture shows about equal proportions of quartz and orthoclase.

Mineralogy: -

Transparents		Opaques	
Orthoclase	20%	Hematite	12%
Quartz (mostly in veins)	30%	Ilmenite	
Oligoclase	4%	Leucoxene	
Calcite (veins)	10%	Limonite	
Sericite	1%		
Epidote	tr		
Amorphous to cryptocrystalline	23%		

Stratigraphic unit: - Andesite member

7. Hand specimen description: - Dark brown, irregularly bedded slate containing fragments of volcanics varying in size from microscopic to several mm in diameter. The well developed folliation allows a deep penetration by weathering. The weathered surface is yellowish green along the folliation planes and very dark green on the outer surface.

Microscopic fabric: - The thin section is almost opaque due to disseminated iron oxides. Fragments of foreign rocks show however good transparency. Some fragments are much altered to chlorite, carbonates, epidote, and limonite. Chloritization is well developed along the folliation surfaces. Albite and orthoclase are the most abundant minerals in the lithic fragments.

Mineralogy: -

Transparents		Opaques	
Orthoclase	6%	Hematite	8%
Albite	7%	Limonite	10%
Quartz	5%	Ilmenite	1%
Calcite	10%	Leucoxene	1%
Chlorite	2%		
Epidote	tr		
Amorphous	50%		

Lithic fragments form 30% of the rock.

Stratigraphic unit: - Andesite member

8. Hand specimen description: - Volcanic breccia formed by varicolored constituents well cemented by a grayish green matrix. The constituents which are gray, red, brown, and white form 80% of the rock; they are fragments of rhyolitic volcanic rocks. The matrix forms 20% of the rock.

Microscopic fabric: - Some fragments of rhyolite show orthoclase phenocrysts and laths of plagioclase in a microcrystalline groundmass of quartz and plagioclase; orthoclase phenocrysts show overgrowth rims and incipient alteration to sericite. Other fragments contain epidote and chlorite as alteration products of former pyroxene or amphibole crystals. Still others have a considerable amount of hematite and leucoxene. The matrix of the rock contains some phenocrysts of quartz, orthoclase, and plagioclase in a cryptocrystalline groundmass which is much altered to sericite and carbonates.

Mineralogy: -

Transparents		Opaques	
Quartz	30%	Hematite	tr

Mineralogy (contl): -

Orthoclase	20%	Limonite	tr
Albite	5%	Ilmenite	tr
Calcite	6%	Leucoxene	1%
Sericite	1%	Magnetite	1%
Epidote	tr		
Amorphous	36%		

Stratigraphic unit: - Upper Rhyolite member

9. Hand specimen description: - Mottled, purplish brown and light green aphanitic rock cut by small fracture filling veinlets. The rock shows slickensided surface which is weathered to a brownish yellow color. The external weathered surface is of a pinkish yellow color recovered by a thin veneer of quartz after removal of other minerals by weathering.

Microscopic fabric: - In thin section 2 sets of fractures filled with quartz can be observed; one very well developed with the fractures perfectly parallel; the other set not so well developed making a 65 degree angle with the first. Crystallized quartz is present mostly in fractures forming veins. The orthoclase and plagioclase present in the cryptocrystalline mass of the rock have been partly altered to sericite and carbonates.

Mineralogy: -

Transparents		Opaques	
Quartz	30%	Hematite	tr
Orthoclase	15%	Limonite	1%
Albite	3%	Leucoxene	tr
Carbonates	8%		
Sericite	3%		
Amorphous	40%		

<u>Stratigraphic unit</u>: - Upper Rhyolite member

10. <u>Hand specimen description</u>: - Dark brownish red aphanitic felsite showing abundant fracture filling veins of quartz. The weathered surface is of a yellowish brown color.

<u>Microscopic fabric</u>: - The powdered hematite disseminated all through the rock makes it red under the microscope. In places the amount of hematite is enough to make the rock almost opaque. Sometimes fragments of the rock are enclosed in the quartz of the veins. With exception of the veins where the crystals of quartz and plagioclase are well developed the rock shows an amorphous to cryptocrystalline texture. In places the hematite is concentrated in small patchy masses. Microscopic displacements of the quartz veins are sometimes observed.

<u>Mineralogy</u>: -

Transparents		Opaques	
Quartz (veins)	20%	Hematite	10%
Orthoclase	2%	Leucoxene	tr
Albite	1%		
Carbonates	3%		
Amorphous	64%		

<u>Stratigraphic unit</u>: - Upper Rhyolite member

11. <u>Hand specimen description</u>: - Greenish gray to dark gray, aphanitic rock, with abundant veinlets of epidote. Locally the predominancy of epidote confers to the rock a pistachio green color. The weathered surface

of the rock is dark gray to black.

Microscopic fabric: - Deeply altered microcrystalline mafic rock with abundant plagioclase microlites. The original ferromagnesian has been completely altered to epidote, chlorite and carbonates. The plagioclase is also deeply altered with only the more sodic fraction remaining.

X-ray powder picture shows absolute predominancy of plagioclase with chlorite.

Mineralogy: -

Transparents		Opaques	
Oligoclase	30%	Ilmenite	2%
Saussurite	20%	Leucoxene	5%
Chlorite	18%	Magnetite	2%
Carbonates	3%		
Amorphous	20%		

Stratigraphic unit: - Basalt member

12. Hand specimen description: - Dark green aphanitic rock cut by numerous veinlets of epidote. Incipient conchoidal fracture. The weathered surface of the rock is yellowish green.

Microscopic fabric: - The specimen shows an almost complete alteration. It has an amorphous to cryptocrystalline texture. The present composition of the plagioclase is that of oligoclase, but it may have been labradorite in the original rock. The products of alteration of the plagioclase and ferromagnesian minerals are chlorite, saussurite and carbonates. The walls of some veins are recovered by a thin layer of epidote and the veins are filled with calcite.

X-ray powder picture shows abundance of plagioclase with chlorite and quartz.

Mineralogy: -

Transparents		Opaques	
Oligoclase	15%	Magnetite	3%
Saussurite	12%	Leucoxene	4%
Chlorite	10%		
Carbonates	5%		
Quartz (veins)	5%		
Amorphous	46%		

Stratigraphic unit: - Basalt member

13. Hand specimen description: - Mottled purplish dark brown and green porphyritic tuffaceous rock. Phenocrysts of orthoclase (6%) and plagioclase (8%) in an aphanitic groundmass. Patches of green chloritic alterations. Limonite stains. The weathered surface is yellowish brown.

Microscopic fabric: - Ferruginous, porphyritic rock formed by phenocrysts of plagioclase and orthoclase immersed in an amorphous to cryptocrystalline groundmass. The orthoclase as well as the plagioclase is deeply altered. The products of alteration are sericite, carbonates, and chlorite. The fragments of foreign rock, which form about 40% of the total, have essentially the same composition as the host rock, but have a better crystallised groundmass showing microlites of plagioclase and are much less ferruginous.

The overall rock, however, contains a considerable amount of disseminated iron and titanium oxides, which makes it almost completely opaque in places.

Mineralogy: -

Transparents		Opaques	
Albite	25%	Leucoxene	5%
Orthoclase	20%	Hematite	10%
Calcite	5%	Limonite	1%
Chlorite	tr	Ilmenite	2%
Sericite	tr	Magnetite	2%
Amorphous	30%		

Stratigraphic unit: - Andesite member

14. Hand specimen description: - Dark gray, porphyritic rock showing well developed crystals of pyrite. The phenocrysts of plagioclase (15%) and orthoclase (5%) are immersed in an aphanitic groundmass. The weathered zone is a thin layer of whitish kaolinitic material with its external surface of a dull yellowish brown color.

Microscopic fabric: - The phenocrysts of orthoclase and plagioclase which have been much altered are contained in an amorphous to cryptocrystalline groundmass. Phenocrysts with the outline of an amphibole have been completely replaced by chlorite and calcite. Plagioclase and orthoclase are altered to carbonates and sericite.

Mineralogy: -

Transparents		Opaques	
Oligoclase	20%	Leucoxene	tr
Orthoclase	10%	Magnetite	tr
Calcite	25%	Pyrite	tr

Mineralogy (cont.):

Chlorite	15%
Sericite	tr
Amorphous	30%

Stratigraphic unit: - Andesite member

NEWBURY VOLCANICS

LEGEND

Sb — Basalt

Sru — Upper Rhyolite

Sa / Sac — Andesite with conglomerate and slate

Srl — Lower Rhyolite

Basement complex

Wrench Fault

U / D — Normal Fault

Member and Formation boundary

Facies boundary

40 / 60 — Bedding

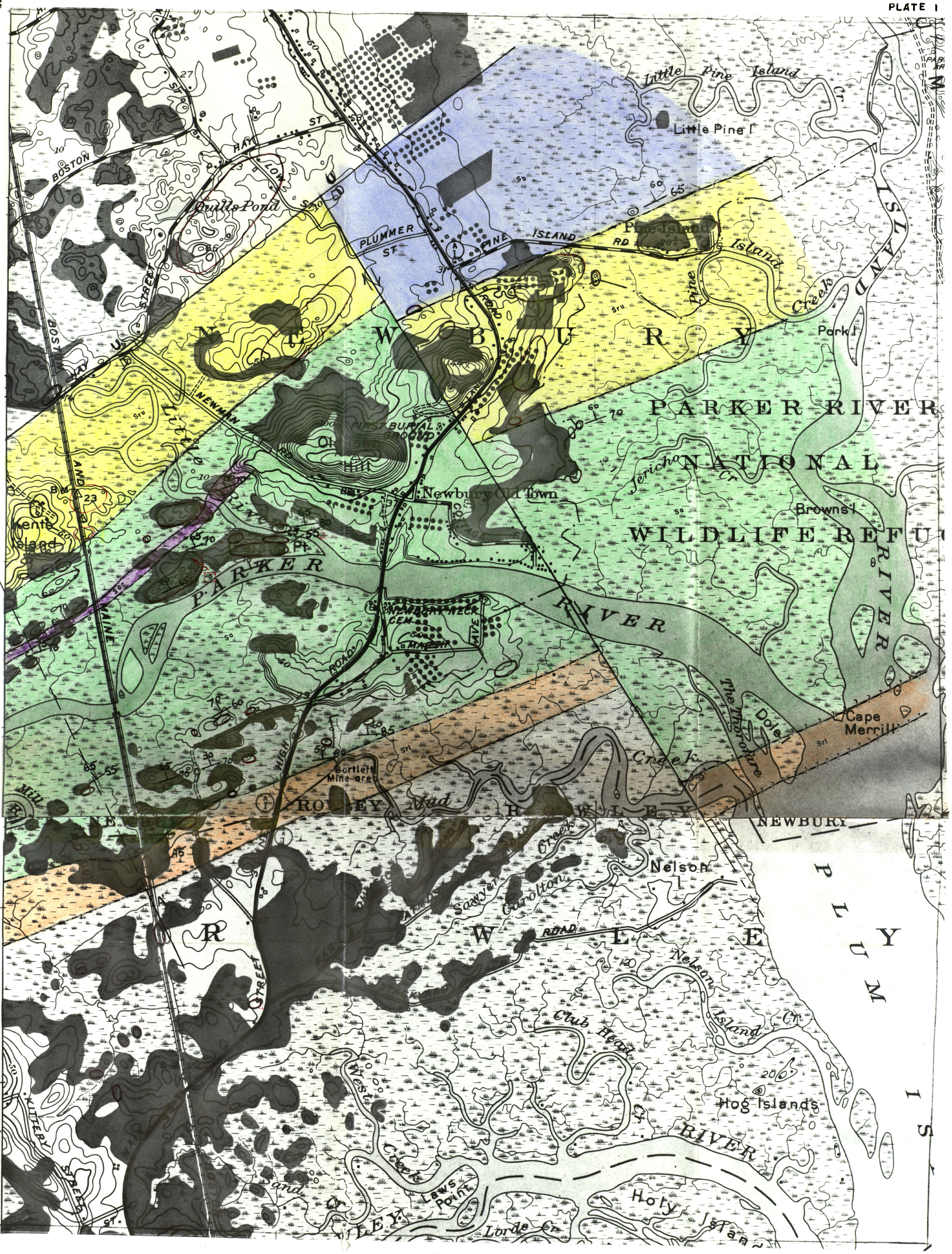
40 / 60 — Cleavage

Outcrop

5 — Thin Section number

Cross Section

Scale: 6" = 1 mile



Edson Rebelo dos Santos

May 21, 1960

NEWBURY VOLCANICS

LEGEND

Sb
Basalt

Sru
Upper Rhyolite

Sa
Sac
Andesite with conglomerate and slate

Srl
Lower Rhyolite

Basement Complex

Wrench Fault

U
D
Normal Fault

Member and Formation boundary

Facies boundary

40
60
Bedding

40
60
Cleavage

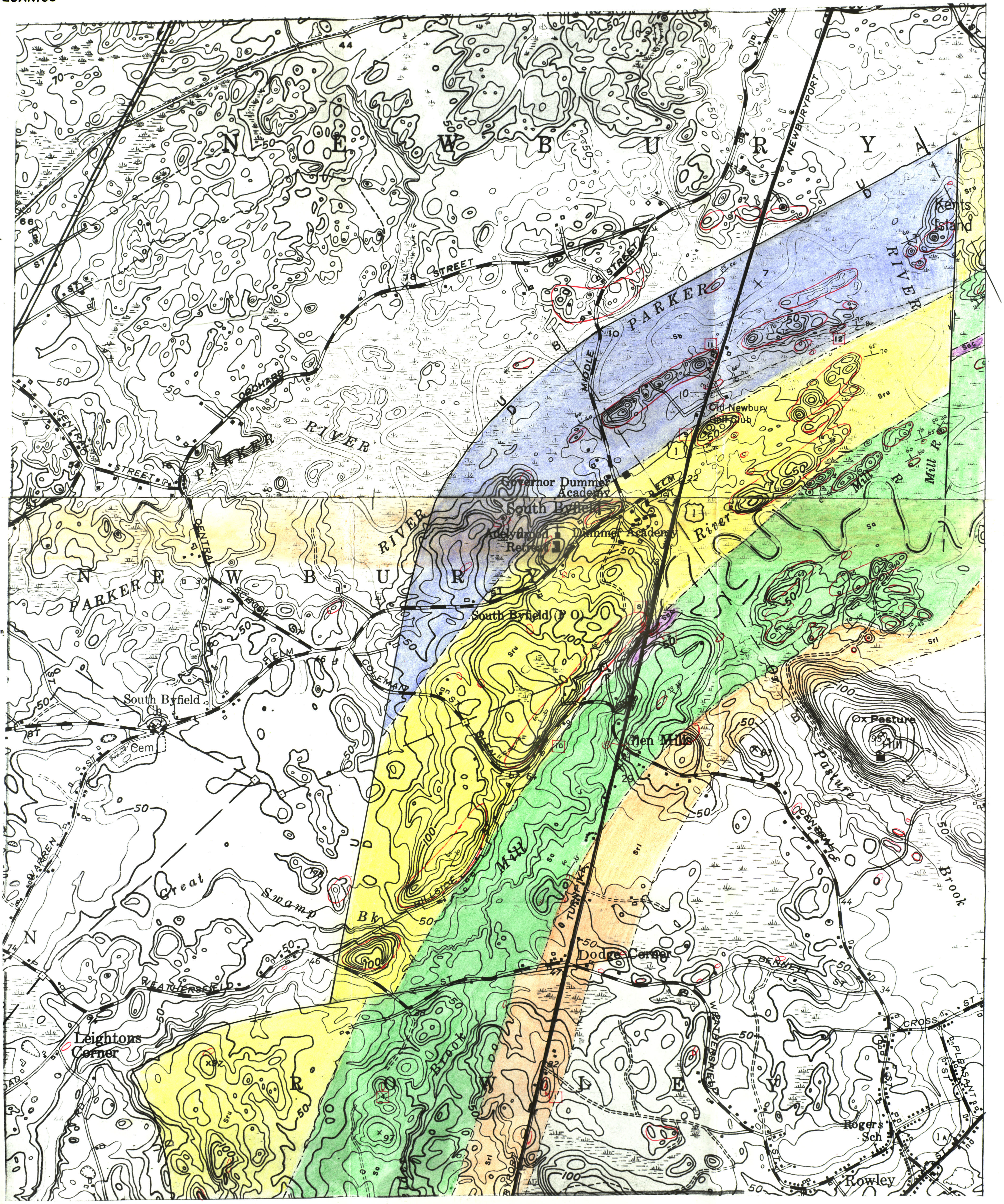
Fossil Locality

Outcrop

4
Thin Section number

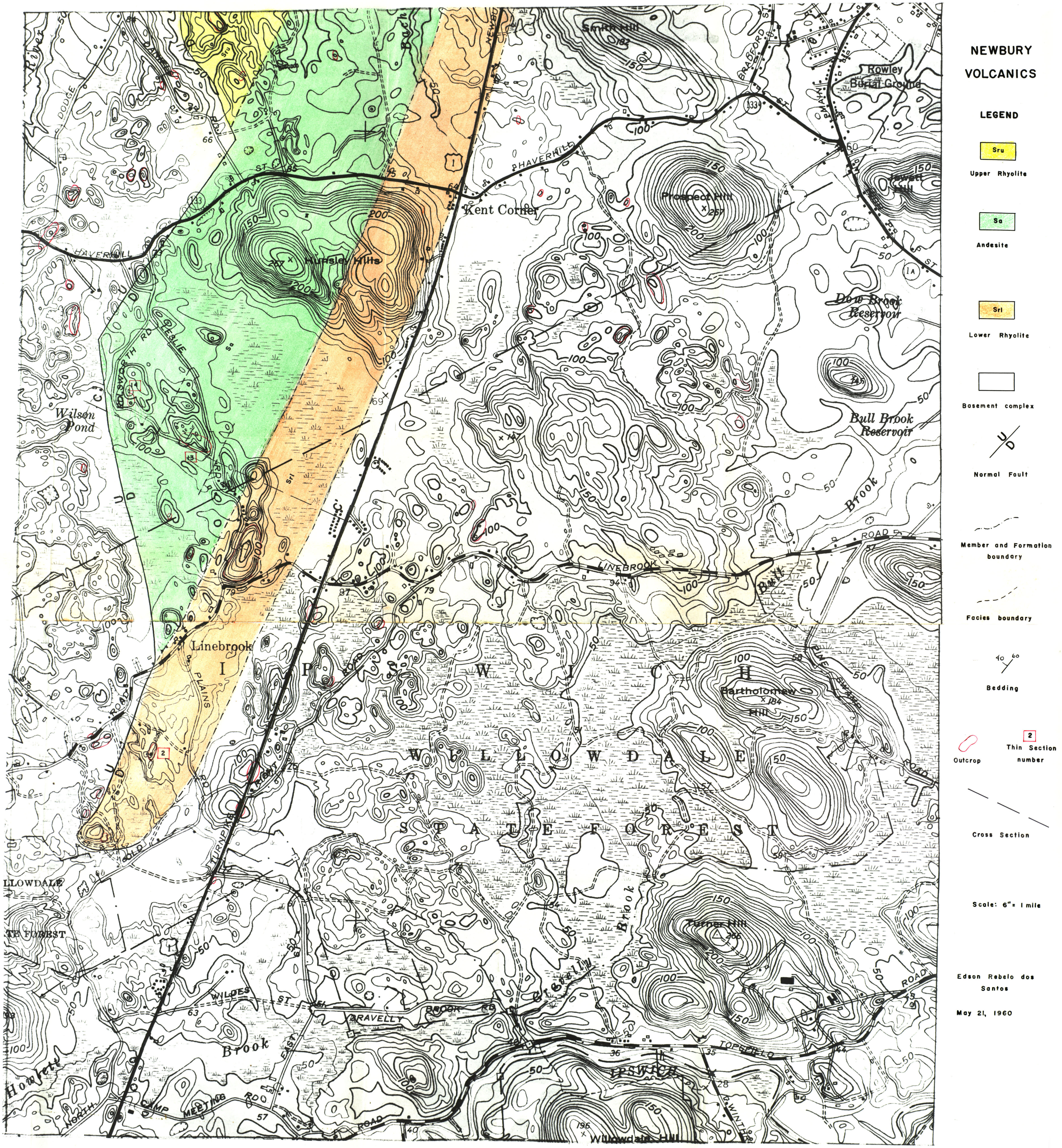
Cross Section

Scale: 6" = 1 mile

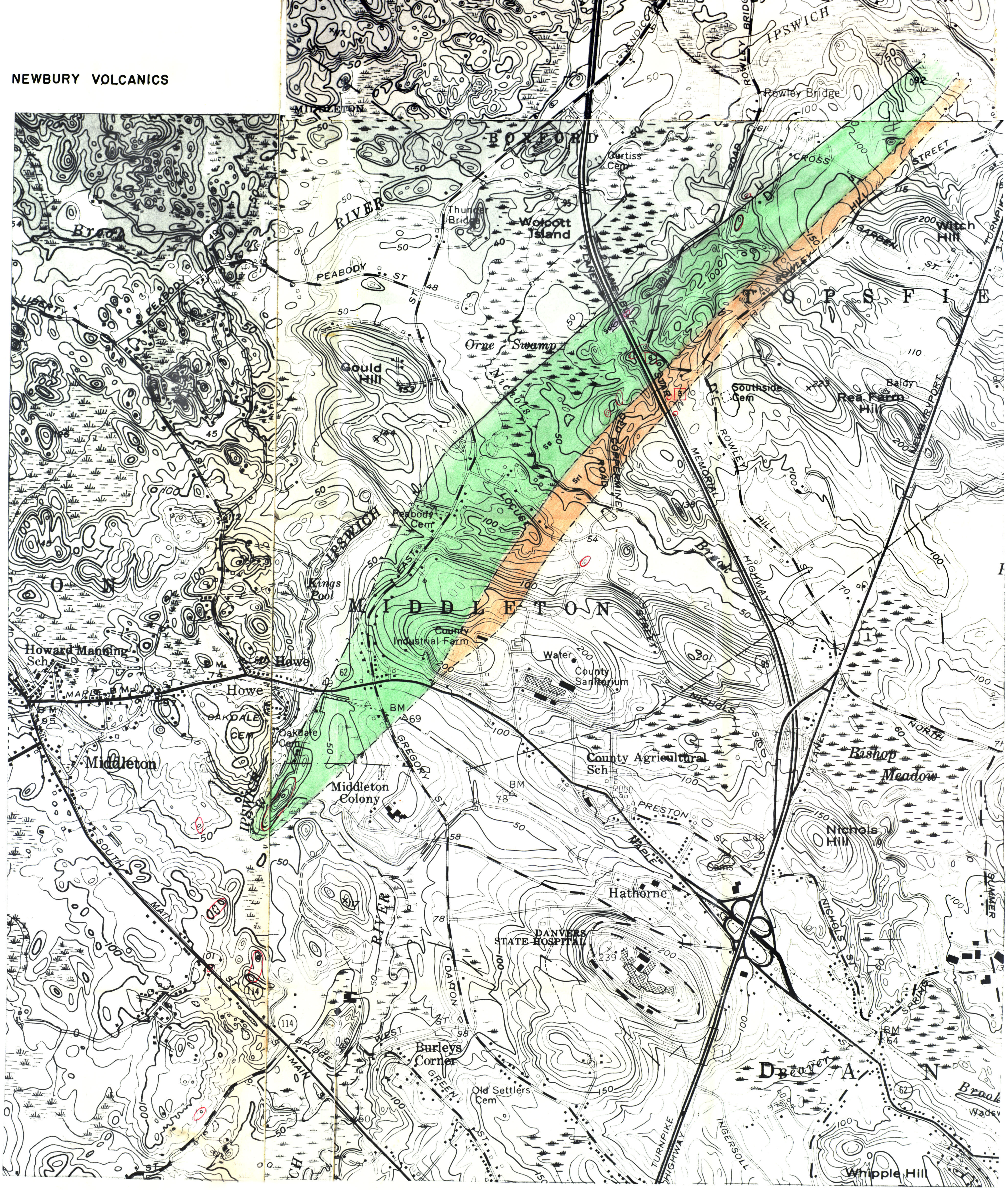


Edson Rebelo dos Santos

May 21, 1960


NEWBURY
VOLCANICS
LEGEND
Sru
Upper Rhyolite
Sa
Andesite
Srl
Lower Rhyolite
Basement complex
Normal Fault
Member and Formation boundary
Facies boundary
Bedding
Outcrop
Thin Section number
Cross Section
Scale: 6" = 1 mile
Edson Rebelo dos Santos
May 21, 1960
Smith Hill
Rowley Burial Ground
Kent Corner
Prospect Hill
Hunsley Hills
Dow Brook Reservoir
Bull Brook Reservoir
Wilson Pond
Linebrook
IPSWICH
Bartholomew Hill
WILLOWDALE
STATE FOREST
Turner Hill
Willowdale Hill
Gravelly Brook

NEWBURY VOLCANICS



LEGEND

Sa
Sac

Andesite with conglomerate and slate

Srl

Lower Rhyolite

Basement complex

U
D

Normal Fault

Member and Formation boundary

Facies boundary

Fossil locality

Outcrop

3

Thin Section number

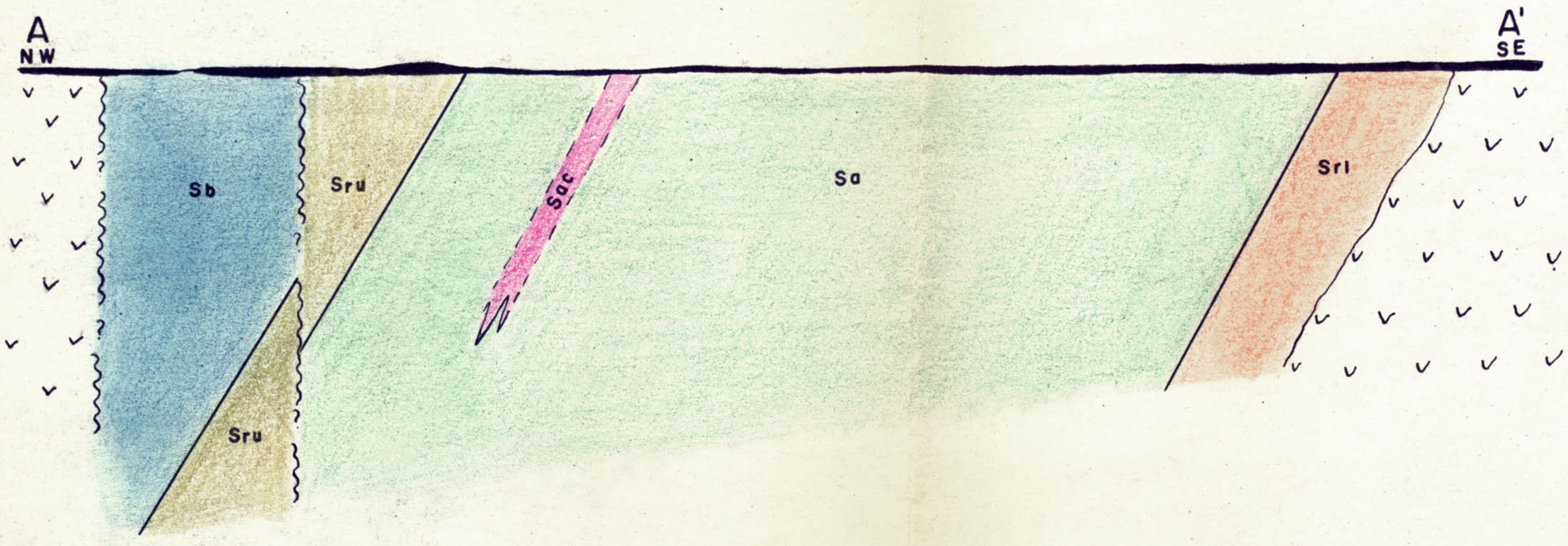
Scale: 6" = 1 mile

Edson Rebelo dos Santos

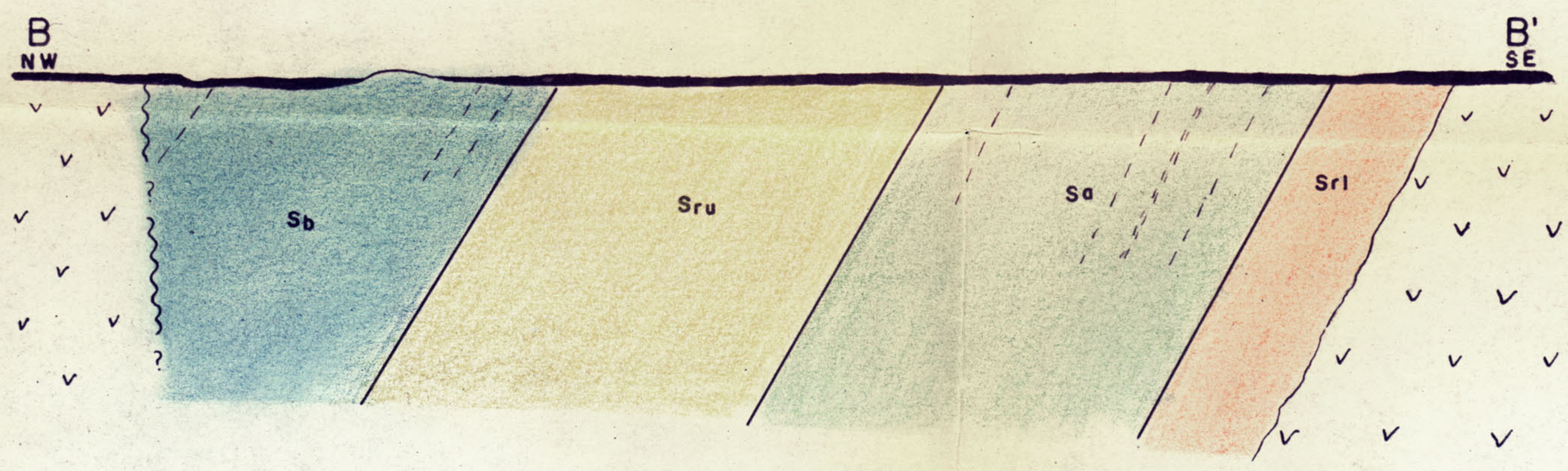
May 21, 1960

NEWBURY VOLCANICS

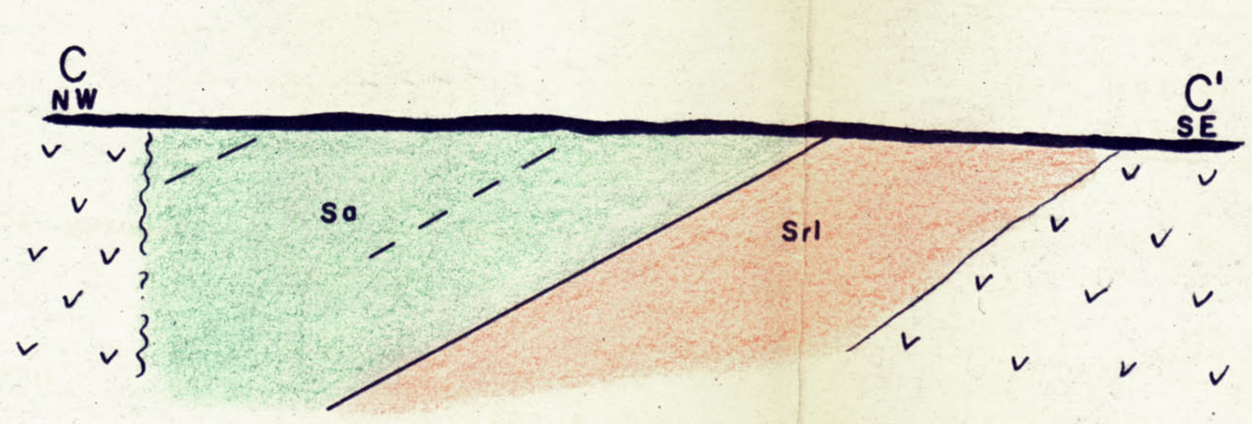
Cross Sections



Cross Section A-A'



Cross Section B-B'



Cross Section C-C'

LEGEND

Sb Basalt

Sa Sac Andesite with Cgl. and Slate

Basement

Assumed fault of unknown attitude

Sru Upper Rhyolite

Srl Lower Rhyolite

SCALE: 6" = 1mile

Edson Rebelo dos Santos
May 21, 1960


71° 15'
71° 00'
70° 45'
42° 45'
42° 30'
42° 15'
ATLANTIC OCEAN
BOSTON BAY
NEWBURYPORT
NEWBURY OLD TOWN
PARKER RIVER
Governor Dummer Academy
Glen Mills
Dodge Corner
ROWLEY
Kent Corner
Linebrook
Hood Pond
IPSWICH
Ipswich River
TOPSFIELD
Nichol Brook
Chebacco Lake
Martin Pond
Swan Pond
Middleton Pond
MIDDLETON
Wenham Lake
Martin's Brook
DANVERS
Bruce's outcrop
Danvers River
READING
Pilling's Pond
PEABODY
WAKEFIELD
MARBLEHEAD
Marblehead Neck
Crystal Lake
Walden Pond
Burbank Pond
Birch Pond
WOBURN
Horn Pond
MELROSE
SAUGUS
LYNN
WINCHESTER
LEXINGTON
Reservoir
MALDEN
MEDFORD
ARLINGTON
Hardys Pond
BELMONT
Fresh Pond
SOMERVILLE
Mystic River
CAMBRIDGE
Charles River
BOSTON
NEWTON
BROOKLINE
Route 1
New York New Haven and Hartford R.R.
Boston and Maine R.R.
Newburyport Turnpike
NEEDHAM
Neponset River
QUINCY
MILTON
LEGEND
Map showing the distribution of the Newbury volcanics and their relation to the volcanics of the Boston area
Newbury volcanics
Basalt
Upper Rhyolite
Andesite
Lower Rhyolite
Lynn volcanics
Mattapan volcanics
"Marlboro Formation"
Woburn Formation
Distribution of the rocks of the Boston area is based on La Forge's and Bell's works
SCALE:
1" = 1 mile
0
1 mi
Edson Rebelo dos Santos
May 21, 1960

GEOLOGIC MAP OF THE HOPPIN HILL AREA

Showing intercalations of the volcanics in the Carboniferous Wamsutta Formation

After Coomaraswamy

LEGEND

Cri
Rhode Island Formation
Quartz conglomerate with much red slate

Cwr
Rhyolite Porphyry
Red aphanitic groundmass with quartz and orthoclase phenocrysts. Agglomerate at the base

Cwb
Basalt Lava
Green-black aphanitic groundmass with vesicules and calcite amygdules

Cw
Wamsutta Formation
Red conglomerate with quartzite, rhyolite, basalt, and granite pebbles. Ss and Sh lenses

Cp
Pondville Formation
Gray basal conglomerate with milky quartz veins

Ꞓh
Hoppin Formation
Red slaty beds with fossiliferous limestone nodules and quartz lenses deposited over a basal quartzite

Pre-Ꞓd
Dedham Granodiorite
A hornblende-biotite granite porphyry with phenocrysts of orthoclase


71° 30'
15'
71° 00'
45'
70° 30'
45'
42° 30'
15'
42° 00'
45'
41° 30'
Newburyport
Newbury Old Town
Byfield
Parker River
Georgetown
Rowley
Rowley River
Ipswich
Boxford
River
Topsfield
Ipswich
Middleton
6
Reading
Salem
Peabody
Marblehead
Marblehead Neck
Woburn
Saugus
Lynn
Arlington
Cambridge
Charles River
BOSTON
BOSTON BAY
Newton
Neponset River
ATLANTIC OCEAN
Brockton
North Attleboro
Attleboro
Taunton
Pawtucket
PROVIDENCE
NARRAGANSETT BAY
LEGEND
INDEX MAP
Map in scale 1"= 1mile
Map in scale 6"= 1mile
SCALE: 1:250000
10 miles
Edson Rebelo dos Santos
May 21, 1960